

*SENSITIVITY OF CONDITIONAL-DISCRIMINATION PERFORMANCE TO WITHIN-SESSION
VARIATION OF REINFORCER FREQUENCY*

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The present experiment developed a methodology for assessing sensitivity of conditional-discrimination performance to within-session variation of reinforcer frequency. Four pigeons responded under a multiple schedule of matching-to-sample components in which the ratio of reinforcers for correct S_1 and S_2 responses was varied across components within session. Initially, five components, each arranging a different reinforcer-frequency ratio (from 1:9 to 9:1), were presented randomly within a session. Under this condition, sensitivity to reinforcer frequency was low. Sensitivity failed to improve after extended exposure to this condition, and under a condition in which only three reinforcer-frequency ratios were varied within session. In a later condition, three reinforcer-frequency ratios were varied within session, but the reinforcer-frequency ratio in effect was differentially signaled within each component. Under this condition, values of sensitivity were similar to those traditionally obtained when reinforcer-frequency ratios for correct responses are varied across conditions. The effects of signaled vs. unsignaled reinforcer-frequency ratios were replicated in two subsequent conditions. The present procedure could provide a practical alternative to parametric variation of reinforcer frequency across conditions and may be useful in characterizing the effects of a variety of manipulations on steady-state sensitivity to reinforcer frequency.

Key words: conditional discrimination, sensitivity, within-session variation of reinforcer frequency, signaled reinforcer-frequency ratios, choice, key peck, pigeon

The study of choice has been central to many research questions within the experimental analysis of behavior. Choice is often studied using the concurrent-schedules procedure, in which two response options are available, and responses to each option produce food according to a separate variable-interval schedule of reinforcement. Within this paradigm, the relation between reinforcer frequency and behavioral allocation has often been described by the generalized matching law (Baum, 1974). In logarithmic form, this relation is

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{R_1}{R_2}\right) + \log c \quad (1)$$

where B_1 and B_2 are the number of responses on each respective choice option and R_1 and R_2 are the number of reinforcers obtained for those responses. $\log c$ quantifies any inherent bias for one choice response option over the other that is independent of variation in reinforcer frequency, and a quantifies the degree to which variations in reinforcer allocation produce concomitant changes in response allocation, termed sensitivity (Lobb & Davison, 1975). Data from numerous studies of choice using the concurrent-schedules paradigm are well described by the generalized matching law (see Davison & McCarthy, 1988, for review and discussion).

Davison and Tustin (1978) proposed a model of conditional-discrimination performance based on the assumptions of the generalized matching law. In a conditional-discrimination procedure, reinforcement for selection of a comparison stimulus depends on the value of a prior sample stimulus. The Davison-Tustin model treats the choice point (presentation of the comparison stimuli) in conditional-discrimination procedures as two concurrent reinforcement–extinction schedules each signaled by a different stimulus. The possible combinations of stimuli and responses in a given conditional-discrimina-

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		Responses	
		B ₁	B ₂
Stimuli	S ₁	11 (correct)	12 (incorrect)
	S ₂	21 (incorrect)	22 (correct)

Fig. 1. Combinations of sample stimuli, comparison-choice responses, and trial outcomes in a conditional-discrimination procedure.

tion procedure are presented in Figure 1. On trials in which S_1 is presented, responses to B_1 are reinforced and responses to B_2 are not reinforced. On trials in which S_2 is presented, the opposite response reinforcer contingency is in effect.

According to Equation 1, the ratio of responses to B_1 and B_2 should equal the ratio of reinforcers (R_1/R_2) obtained for responding on those alternatives, modified according to the parameters $\log c$ and a . An additional consideration in conditional-discrimination experiments is the degree to which the sample stimuli are discriminable from one another. Because only choice responses that match the presented sample stimulus are reinforced in most cases, on trials in which S_1 is presented, choice will favor B_1 , and vice versa. The more discriminable S_1 is from S_2 , the greater will be the choice for B_1 or B_2 when the comparisons are presented. For example, a procedure in which S_1 is green and S_2 is red may result in more differential responding to B_1 and B_2 than a procedure in which S_1 is green and S_2 is blue (due to the greater difference in wavelength between green and red when compared with the difference between green and blue). Thus, the response ratio following S_1 presentations is governed by the reinforcer ratio according to

$$\log \left(\frac{B_{11}}{B_{12}} \right) = a \log \left(\frac{R_{11}}{R_{22}} \right) + \log c + \log d \quad (2a)$$

and the relation between response and rein-

forcer ratios following S_2 presentations is described by

$$\log \left(\frac{B_{21}}{B_{22}} \right) = a \log \left(\frac{R_{11}}{R_{22}} \right) + \log c - \log d \quad (2b)$$

where a and $\log c$ are as defined above, and the subscripts for B and R are the cells depicted in the matrix in Figure 1 (i.e., the first digit identifies which stimulus is presented, and the second digit identifies which response is made). The $\log d$ parameter reflects the degree of discriminability between the sample stimuli. This parameter is essentially a biasing term in the same way as $\log c$. Whereas $\log c$ reflects inherent bias, $\log d$ reflects the biasing effect of the presented sample stimulus. Note that because the numerators in both Equations 2a and 2b are B_1 responses, $\log d$ is positive in Equation 2a and negative in Equation 2b.

A point estimate of discrimination accuracy can be obtained from the Davison-Tustin model by algebraic subtraction of Equations 2a and 2b:

$$\log d = 0.5 \log \left(\frac{B_{11}B_{22}}{B_{12}B_{21}} \right), \quad (3)$$

where all notation is as above. $\log d$ (discriminability; Equation 3) reflects the discriminability between S_1 and S_2 and is free of bias for one comparison stimulus over the other or for any biasing effects of the reinforcer differential. This measure is equivalent to the discriminability index proposed by Luce (1963) and has similar properties as d' from classic detection theory (Green & Swets, 1966). Algebraic addition of Equations 2a and 2b gives a measure of response bias:

$$\begin{aligned} \log b &= 0.5 \log \left(\frac{B_{11}B_{21}}{B_{12}B_{22}} \right) \\ &= a \log \left(\frac{R_{11}}{R_{22}} \right) + \log c, \end{aligned} \quad (4)$$

where all notation is as above. Thus, $\log b$ (the tendency to choose one comparison stimulus over the other regardless of the presented sample stimulus) is a function of the reinforcer differential and inherent bias. $\log b$ is theoretically independent of the discriminability of the sample stimuli ($\log d$).

A substantial amount of research has focused on the application of matching-law based models of conditional-discrimination performance to data obtained from a variety of conditional-discrimination procedures (see Davison & Nevin, 1999; Nevin, Davison, & Shahan, 2005, for reviews). Most previous investigations have parametrically varied reinforcer-frequency ratios across conditions; i.e., each reinforcer ratio is in place for a number of sessions until choice stabilizes (but see Hobson, 1978), similar to traditional studies with simple concurrent schedules. Recent investigations, however, have demonstrated that choice responding in simple concurrent schedules is sensitive to within-session variations in reinforcer frequency. For example, Davison and Baum (2000) exposed pigeons to a 7-component mixed schedule (components were separated by 10-s blackouts and were not differentially signaled) in which the ratio of reinforcers allocated to two concurrent-schedule response options was varied across components from 1:27 to 27:1. They reported that reliable and stable estimates of sensitivity to the across-component variation of reinforcer ratios could be obtained in one session. These results have been replicated in numerous experiments (e.g., Aparicio & Baum, 2006; Davison & Baum, 2002, 2003, 2007; Krägeloh & Davison, 2003; Landon & Davison, 2001).

There is some evidence that choice responding in conditional-discrimination procedures may be sensitive to rapid variations in reinforcer frequency. For example, Hobson (1978) trained 3 pigeons on a conditional-discrimination procedure in which they discriminated between having completed a small or large fixed-ratio (FR) requirement by subsequently pecking a left or right response key. She then manipulated the reinforcement magnitude and/or frequency ratios for correct comparison-choice responses. Conditions differed across pigeons with regard to the specific FR values, reinforcement manipulations (magnitude vs. frequency), and the frequency with which reinforcer magnitude or probability was varied (across or within sessions), among other variables. Hobson reported that for one pigeon, choice responding was reliably biased by within-session variations in reinforcer magnitude. For another pigeon, choice responding was reliably biased by within-session variation of reinforcer frequency. These results

suggest that choice responding in conditional discrimination can be sensitive to rapid changes in reinforcer magnitude or frequency, at least under some conditions. The results reported by Hobson, together with the results from the mixed concurrent-schedules procedures reported by Davison and colleagues (e.g., Davison & Baum, 2000, 2002, 2003, 2007), invite assessment and characterization of sensitivity to within-session variations in reinforcer frequency in conditional discrimination.

There are several potential benefits of assessing sensitivity to within-session variation of reinforcer frequency. Aside from the obvious practical benefits of decreasing experimental timelines, a procedure in which estimates of sensitivity can be obtained within session would be useful as a way to assess the effects of a variety of manipulations on steady-state sensitivity to reinforcer frequency. In particular, such a procedure would be useful in assessing the effects of manipulations that may differ in their effects as a function of repeated implementation (such as extinction or pharmacological treatments). In the present study, we develop a methodology for such an assessment. Pigeons responded under a conditional-discrimination procedure, based on the procedure used by Davison and Baum (2000) for simple concurrent schedules, in which reinforcer-frequency ratios for correct choice responses were varied across components of a mixed schedule from 1:9 to 9:1. Because the measures of $\log d$ (Equation 3) and a (Equation 4) are widely used to describe the effects of various manipulations on conditional-discrimination performance and sensitivity to variation of reinforcer frequency (see Nevin et al., 2005, for review), these measures were used in the present paper to characterize the effects of within-session variation of reinforcer frequency.

METHOD

Subjects

Four homing pigeons that had prior experience with delayed matching-to-sample (DMTS) procedures served as subjects. Pigeons were maintained at $80\% \pm 15$ g of their free-feeding weight by postsession feeding as needed. Between sessions, pigeons were individually housed with free access to water in a temperature-controlled colony under a 12:12 hr light/dark cycle. Experimental ses-

sions were conducted 7 days per week at approximately the same time.

Apparatus

Four Lehigh Valley Electronics sound-attenuating chambers were used. Chambers were constructed of painted metal with aluminum front panels. The chambers measured 30 cm across, 35 cm deep, and 35 cm high. Each front panel had three translucent plastic keys that could be lit from behind with red, green, white, yellow, and turquoise light and required a force of at least 0.10 N to record a response. Keys were 2.5 cm in diameter and 24 cm from the floor. A lamp (28 V, 1.1 W) mounted 4.5 cm above the center key served as a houselight. A rectangular opening 8.5 cm below the center key provided access to a solenoid-operated hopper filled with pelleted pigeon chow. During hopper presentations, the opening was lit with white light. White noise and chamber ventilation fans masked extraneous noise. Contingencies were programmed and data collected by a microcomputer using Med Associates® interfacing and software.

Procedure

As all pigeons had previous experience with related procedures, no hopper or key peck training was necessary. During initial training, sessions began with the illumination of the houselight and illumination of the center key with either turquoise (S_1) or white (S_2). These sample colors were chosen because the pigeons had no prior experience with them. S_1 and S_2 were selected randomly from trial to trial with the constraint that each sample stimulus could not be presented on more than 10 consecutive trials. A peck to the center key extinguished it and lit the side keys, one turquoise and one white (comparison stimuli). The location of each key color (left or right key) was randomly determined from trial to trial. A peck to the key color that matched the presented sample color produced 2-s access to food, while a peck to the nonmatching key color resulted in a 2-s blackout. Sessions ended after 60 trials, 30 with S_1 and 30 with S_2 .

Initially, correct choice responses were reinforced with a probability of 0.5 and there was no intertrial interval (ITI). Under these conditions, discrimination accuracy was poor. Accordingly, the probability of reinforcement

for correct choice responses was increased to 1.0 and a 5-s ITI was implemented. If at any time during this initial training phase accuracy was low because of a pronounced color or side bias a correction procedure was implemented. During sessions in which this procedure was in place an incorrect choice response produced a 2-s blackout, after which the entire trial was repeated, with the same sample stimulus and comparison stimuli in the same locations. This process continued until a correct choice response terminated the trial in food. All pigeons experienced correction at some point during initial training (8–10 sessions, across pigeons), but correction was not needed for the remainder of the experiment.

Once matching accuracy was acquired (at least 80% correct over the last five sessions; this criterion was reached in 23–28 sessions, across pigeons), the probability of reinforcement for correct choice responses was decreased from 1.0 to .5 across 10 successive sessions. Once the probability of reinforcement reached .5, reinforcers for correct choice responses were scheduled as follows. At session (or component, see description below) onset and following each reinforcer presentation, the next reinforcer was assigned to a correct S_1 or S_2 response with a fixed probability. No other reinforcers were arranged until the scheduled reinforcer was collected (or until the component ended). This way of scheduling reinforcers is a controlled reinforcer ratio procedure and ensures that the programmed reinforcer ratios are similar to the obtained reinforcer ratios (e.g., McCarthy & Davison, 1991). Following an additional 10 sessions, the final procedure was introduced.

The final procedure was a mixed schedule of conditional-discrimination procedures in which the reinforcer-frequency ratio for correct S_1 and S_2 choice responses was varied across components within session. The reinforcer ratio was varied by changing the probability that a reinforcer would be assigned to a correct S_1 or S_2 choice response. For example, in the 9:1 component, correct S_1 choice responses were reinforced with .9 probability, whereas correct S_2 responses were reinforced according to a probability of .1. In all experimental conditions, components were selected randomly without replacement and ended after 20 trials (10 S_1 and 10 S_2). The houselight remained on for the duration of

each component and components were separated by a 10-s blackout. Each component began with a 5-s ITI. Sessions ended after each component was presented once. The experiment consisted of five conditions.

Condition 1: Five unsignaled reinforcer ratios. Five reinforcer ratios (1:9, 1:3, 1:1, 3:1, 9:1) were varied across components. This condition was conducted for 50 sessions. To assess the effects of more extensive exposure, 2 pigeons (216 & 1821) experienced an additional 20 sessions.

Condition 2: Three unsignaled reinforcer ratios. This condition was conducted with 2 pigeons (1188 & 3060) for at least 30 sessions (1188 experienced 32 sessions due to experimenter error). Three reinforcer ratios (1:9, 1:1, 9:1) were varied across components. During this condition and all subsequent ones, the number of trials per component remained as in Condition 1 (20 trials) and so the overall number of trials decreased from 100 to 60.

Condition 3: Three signaled reinforcer ratios. Three reinforcer ratios (1:9, 1:1, 9:1) were varied across components, as in Condition 2. This condition differed from Condition 2, however, in that the reinforcer ratio in effect during each component was differentially signaled by illumination of the three response keys during the 5-s ITI (thus making it a multiple schedule). The colors (red, green, yellow) associated with each component differed across pigeons. This condition was conducted for 70 sessions.

Condition 4: Three unsignaled reinforcer ratios. This condition was a replication of Condition 2 and was conducted for 50 sessions.

Condition 5: Three signaled reinforcer ratios. This condition was a replication of Condition 3 and was conducted for 70 sessions.

Data Analysis

The data collected were the number of correct and incorrect S_1 and S_2 choice responses, and the number of reinforcers delivered for correct S_1 and S_2 choice responses in each component. The response measures from Conditions 1, 2, and 4 (unsignaled reinforcer ratios) were stable as assessed by visual inspection for all pigeons after 10 sessions, whereas the measures from Conditions 3 and 5 (signaled conditions) stabilized after around 30 sessions. In order to assess performance over the same session window, all analyses were

based on data summed over sessions 30–50 of each condition for each pigeon, even though some conditions were conducted for longer. For Condition 2, in which only 30 sessions were conducted (32 for pigeon 1188), data were summed across sessions 10–30.

Discrimination accuracy was calculated as $\log d$ (Equation 3), and response bias (the biasing effect of the reinforcer differential) was calculated as $\log b$ (left side of Equation 4). Estimates of $\log d$ and $\log b$ are in calculable if any cell in Equations 3 or 4, respectively, is zero. Accordingly, we corrected the calculation of both measures by adding 0.25 to the obtained number in each cell for all analyses (e.g., Hautus, 1995; see Brown & White, 2005, for discussion). To obtain estimates of sensitivity of choice responding to variations in reinforcer frequency (a in Equation 4), the obtained estimates of $\log b$ were plotted as a function of the logarithm of the reinforcer-frequency ratio in each component and Equation 4 was fitted to these data.

RESULTS

Figure 2 shows estimates of response bias ($\log b$) as a function of the log reinforcer-frequency ratio across components during Conditions 2–5 for each pigeon (for clarity, data from Condition 1 are presented in the Appendix). The straight lines show the best fits of Equation 4 to the data (variance accounted for and values of a and $\log c$ are displayed in Table 1). Separate linear regressions were conducted for each condition for each pigeon. In general, the results across pigeons were similar. During conditions in which reinforcer ratios across components were unsignaled (Conditions 2 and 4, see also Condition 1), the estimates of response bias were relatively unaffected by variations in reinforcer frequency. Thus, in these conditions, the distribution of choice responses was unchanged by across-component changes in the relative probability of reinforcement for correct S_1 and S_2 responses. In addition, estimates of sensitivity (a) for the 2 pigeons that experienced an additional 20 sessions during Condition 1 (216 and 1821) did not improve as a result of this extended exposure. For pigeon 216, the estimate of sensitivity decreased from 0.17 before extended exposure to -0.07 after. For pigeon 1821, the estimates of sensitivity before

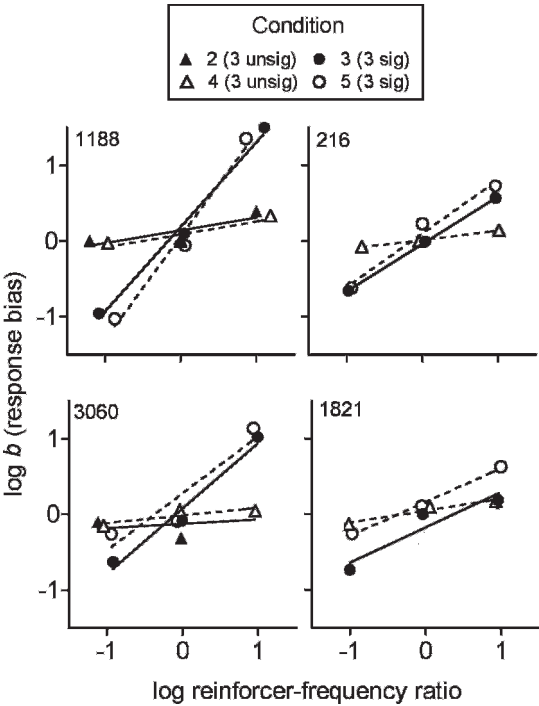


Fig. 2. Estimates of response bias (log *b*, left side of Equation 4) as a function of the log reinforcer-frequency ratio for all pigeons in Conditions 2–5 of the experiment. Straight lines through the data points show the best fits of Equation 4 to the data (see Appendix for individual parameter estimates).

and after extended exposure were 0.04 and 0.02, respectively.

When reinforcer ratios were signaled (Conditions 3 and 5), variations in reinforcer frequency across components had a substantial biasing effect, indicating that choice responses now favored the relatively richer stimulus in each component, even when choice of this stimulus was incorrect. This general result held across pigeons, with the magnitude of the effect being smallest for pigeon 1821. Separate analyses showed that the biasing effects of the reinforcer differential were similar following *S*₁ and *S*₂ trials (data not shown; raw data in Appendix).

Table 1 shows estimates of sensitivity (*a*) obtained from the regressions of Equation 4 on the choice-response data for each condition for each pigeon. During conditions in which reinforcer-frequency ratios were unsignaled (Conditions 1, 2, and 4), estimates of sensitivity were low (0.04–0.17 across pigeons). By contrast, during conditions in which reinforcer-frequency ratios were signaled (Conditions 3 &

Table 1
Estimates of sensitivity (*a*), inherent bias (log *c*), the proportion of variance accounted for by Equation 4, and values of log *d* (averaged across reinforcer-frequency ratios) for all pigeons in all experimental conditions (pigeons 216 and 1821 did not experience Condition 2).

Pigeon	Condition	(<i>a</i>)	log <i>c</i>	R ²	log <i>d</i>
1188	1	0.11	−0.07	0.18	1.67
	2	0.17	0.14	0.70	1.39
	3	1.12	0.18	0.99	0.81
	4	0.17	0.09	0.85	1.38
	5	1.37	0.05	0.98	1.10
216	1	0.17	0.17	0.86	1.63
	2				
	3	0.63	−0.03	1.00	0.79
	4	0.12	0.02	0.99	1.42
	5	0.71	0.10	0.98	0.89
3060	1	0.14	−0.02	0.82	1.38
	2	0.06	−0.12	0.12	1.52
	3	0.81	0.04	0.99	1.38
	4	0.17	0.01	0.95	1.44
	5	1.02	0.29	0.94	1.48
1821	1	0.04	−0.06	0.08	0.87
	2				
	3	0.5	−0.12	0.99	0.56
	4	0.14	0.07	0.99	0.89
	5	0.48	0.11	1.00	0.62

Note. Pigeons 216 and 1821 did not experience Condition 2.

5), estimates of sensitivity were much higher (0.48–1.37 across pigeons).

Figure 3 shows estimates of discriminability (log *d*) plotted as a function of the log reinforcer-frequency ratio (*R*₁₁/*R*₂₂) across components for all pigeons in all conditions of the experiment. Across conditions and pigeons, there was no systematic relation between log *d* and the reinforcer-frequency ratio. We therefore averaged the estimates of log *d* across reinforcer-frequency ratios within each condition to obtain an estimate of discrimination accuracy across conditions. The results of this analysis are presented in Table 1. Estimates of log *d* were somewhat higher during conditions in which reinforcer ratios were unsignaled (Conditions 1, 2, and 4) than during conditions in which reinforcer ratios were signaled (Conditions 3 and 5). The exception was pigeon 3060, which displayed a similar level of discrimination accuracy across conditions.

DISCUSSION

The present study was conducted to assess whether choice responding in conditional

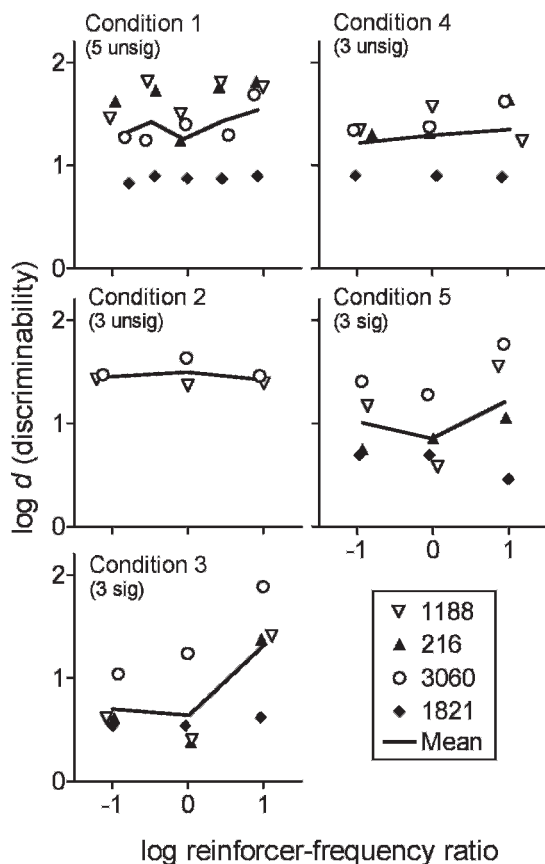


Fig. 3. Estimates of discriminability ($\log d$; Equation 3) as a function of the log reinforcer-frequency ratio across components for all pigeons during all conditions of the experiment.

discrimination would be sensitive to within-session variation of reinforcer frequency. During Condition 1, in which five unsignaled reinforcer-frequency ratios were varied within session, estimates of sensitivity were low. These low values of sensitivity were not likely due to insufficient exposure to the procedure, as estimates of sensitivity decreased after extended exposure. Estimates of sensitivity did not improve during Condition 2 when the number of unsignaled reinforcer ratios was decreased to three. In Condition 3, when the reinforcer ratio in effect during the component was signaled during the ITI, however, estimates of sensitivity increased substantially, and were similar to values of sensitivity obtained when reinforcer ratios are varied across conditions (e.g., Baum, 1983). The effects of unsignaled vs. signaled component reinforcer ratios on

sensitivity were replicated in Conditions 4 and 5, respectively. In addition, across conditions, estimates of discriminability ($\log d$) were independent of variation in the reinforcer-frequency ratios, consistent with the predictions of the Davison-Tustin model and numerous prior results (e.g., McCarthy & Davison, 1980, 1982; Nevin, Cate, & Alsop, 1993).

Independence of discriminability and the reinforcer-frequency ratio in the present data may be perplexing to some readers who are familiar with the differential outcomes effect (DOE) reported in DMTS studies (e.g., Peterson & Traphold, 1980; Traphold, 1970). The DOE manifests as higher discrimination accuracy when different outcomes (e.g., food or water) follow correct S_1 and S_2 responses than when the outcomes for correct S_1 and S_2 responses are the same (e.g., food and food). This effect has also been demonstrated when the different outcomes are different probabilities of reinforcement for correct choice responses, as in the present study (e.g., Nevin, Ward, Jimenez-Gomez, Odum, & Shahan, in press; Santi & Roberts, 1985). Thus, accuracy during the 9:1 and 1:9 components might be expected to be higher than accuracy during the 1:1 component, a result that did not occur. The absence of a DOE in the present study is likely due to the lack of a delay between sample offset and comparison presentation. The DOE is most robust at longer delay intervals, and is often much less apparent at 0-delay intervals (particularly when the differential outcomes are manipulated within-subjects within-session; see Jones & White, 1994; Jones, White, & Alsop, 1995; Nevin et al., in press). Thus, the lack of a DOE here is not without precedent.

In the present experiment, choice responding was reliably biased by variations in reinforcer frequency only when component reinforcer-frequency ratios were signaled. These results differ from those reported by Hobson (1978). She reported a reliable effect of within-session variation of reinforcer magnitude on the measure of bias when changes in reinforcer magnitude were unsignaled (Condition 2, pigeon 366). There were numerous procedural differences between Hobson's study and the present experiment, but one that may be particularly relevant is the number of trials per session. In Hobson's experiment, sessions ended after 400 trials, and reinforcer magnitude varied midway through the session. In the

present experiment, reinforcer ratios changed every 20 trials. Future research might examine if increasing the number of trials per component would increase sensitivity to changing reinforcement ratios.

Another potential explanation for the low sensitivity values obtained in the unsignaled conditions is that the 10-s blackout between components was not a salient enough stimulus to signal a change in the reinforcer frequency ratios, and that sensitivity may have improved in the unsignaled conditions had a more discriminable intercomponent interval (ICI) been employed. Future research could explore this possibility. We consider it unlikely, however, that the salience (or lack thereof) of the ICI employed in the present study was responsible for the lack of sensitivity in the unsignaled conditions, given that the houselight was illuminated for the entirety of each component (20 trials). Therefore, 10-s of chamber blackout following each component was likely to be a salient contrast. Finally, previous studies that have demonstrated sensitivity to unsignaled within-session variation of reinforcer frequency in multiple concurrent schedules have generally arranged a much wider range of reinforcer ratios (1:27–27:1) than is typically arranged across conditions (generally between 1:10–10:1; but see Davison & Jones, 1995). The present experiment arranged reinforcer ratios comparable to those arranged across conditions in previous conditional-discrimination studies (but see Jones, 2003). Future research could assess whether varying reinforcer probabilities over a wider range within session would increase estimates of sensitivity in the unsignaled procedure.

The effects of signaling reinforcer ratios in the present experiment are similar to those reported in concurrent schedules. Using the multiple concurrent-schedules procedure, Krägeloh and Davison (2003) investigated the effects of signaled reinforcer ratios on response bias and sensitivity to reinforcer frequency. In conditions in which reinforcer ratios were signaled (by different frequencies of red–yellow light alternation), overall measures of sensitivity were higher than during conditions in which reinforcer ratios were unsignaled. In the present experiment, the overall estimates of sensitivity were also higher when reinforcer ratios were signaled than when they were unsignaled.

In addition to traditional analyses of performance, recent studies have conducted more local analyses of performance during mixed concurrent-schedules procedures (e.g., Davison & Baum, 2000). These analyses typically pool data over a substantial number of sessions in which performance is at steady state (e.g., 35 sessions) and calculate response measures on a trial-by-trial (or reinforcer-by-reinforcer) basis. In the present experiment, the relatively small number of trials per component (20 total; 10 each of S_1 and S_2) resulted in very few data points with which to conduct a trial-by-trial analysis (and even fewer for conducting a reinforcer-by-reinforcer analysis), even when the data were summed over 20 sessions. We have therefore not presented such an analysis. Future research using this procedure could use more trials per session so that reliable local analyses may be conducted and compared to the results obtained from the mixed concurrent-schedules procedure.

The present procedure may have utility in several areas. First, in typical assessments of sensitivity to reinforcer frequency in conditional discrimination, reinforcer ratios are varied across at least three, and in most cases, five conditions (e.g., 1:9, 1:3, 1:1, 3:1, 9:1). Each reinforcer ratio is typically in place for at least 20 (and generally 30 or more) sessions, for an entire experimental time frame of at least 100 sessions. By contrast, stable estimates of sensitivity can be obtained using the present procedure in 20–30 sessions, thus greatly increasing efficiency and possibly decreasing variability that may occur across conditions. Thus, the present procedure may provide a practical alternative to traditional parametric variation of reinforcer ratios across conditions.

It should be noted that there are currently a number of theoretical models of conditional-discrimination performance aside from the Davison-Tustin model (e.g., Alsop & Davison, 1991; Davison & Nevin, 1999; Jones, 2003; Nevin, Davison, Odum, & Shahan, 2007; White & Wixted, 1999), and the present data do not allow differentiation between them. The purpose of the present article was to provide a practical methodological alternative to traditional variation of reinforcer frequency across conditions. Use of this methodological framework may facilitate and inform future theoretical development.

In addition to its potential usefulness as a tool for future theoretical development, the

present procedure may prove useful in furthering several areas of inquiry. First, the present procedure may prove useful in clarifying the relation between discriminability and sensitivity in DMTS procedures. In contrast to the inverse relation between sensitivity and discriminability found in studies that manipulate the physical disparity between sample stimuli, studies in which the delay between sample and comparison stimuli is manipulated have reported both increasing and decreasing sensitivity as a function of decreasing discriminability (see Nevin et al., 2007 for review). All previous studies of this sort have varied reinforcer ratios across conditions. It would be interesting to assess the relation between discriminability and sensitivity using the present procedure, in which reinforcer ratios are varied within session. In addition, as noted above, the procedure lends itself well to assessing the effects of a variety of disruptors (e.g., prefeeding, extinction, pharmacological manipulations) on steady-state sensitivity to reinforcer frequency. In this regard, it would be of particular interest to see if the positive relation between reinforcer frequency and resistance to disruption that is found with response rates and discrimination accuracy (see Nevin & Grace, 2000; Nevin et al., 2005 for reviews) holds for sensitivity to reinforcer frequency in conditional discrimination. This line of inquiry may help to elucidate and clarify the role of reinforcement variables in performance under relatively simple and more complex operant contingencies.

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APPENDIX

The number of responses to each choice alternative and the number of reinforcers obtained for correct responses following S_1 and S_2 presentations for all pigeons in all conditions of the experiment (pigeons 216 and 1821 did not experience Condition 2). Also shown are estimates of $\log d$ (Equation 3) and $\log b$ (Equation 4).

Pigeon	Condition	Component	B ₁₁	B ₁₂	B ₂₂	B ₂₁	R ₁₁	R ₂₂	log <i>d</i>	log <i>b</i>
1188	1	1:9	194	6	193	7	17	183	1.459	0.033
		1:3	193	7	199	1	48	163	1.814	−0.39
		1:1	193	7	195	5	92	113	1.498	−0.07
		3:1	196	4	198	2	136	49	1.805	−0.14
		9:1	198	2	195	5	180	18	1.758	0.187
	2	1:9	193	7	193	7	11	180	1.43	0.00
		1:1	192	8	192	8	98	98	1.37	0.00
		9:1	197	3	182	18	174	17	1.39	0.39
	3	1:9	62	138	195	5	12	146	0.612	−0.96
		1:1	152	48	133	67	77	68	0.398	0.101
		9:1	200	0	90	110	193	14	1.408	1.495
	4	1:9	191	9	192	8	19	175	1.341	−0.03
		1:1	195	5	195	5	103	103	1.57	0.00
		9:1	195	5	178	22	189	12	1.237	0.333
	5	1:9	116	84	199	1	22	162	1.171	−1.03
		1:1	154	46	163	37	88	76	0.582	−0.06
		9:1	200	0	123	77	172	23	1.553	1.35
216	1	1:9	196	4	195	5	19	174	1.617	0.047
		1:3	197	3	196	4	53	140	1.724	0.059
		1:1	192	8	186	14	87	108	1.242	0.126
		3:1	198	2	195	5	137	52	1.758	0.187
		9:1	199	1	193	7	180	22	1.814	0.388
	2	1:9								
		1:1								
		9:1								
	3	1:9	95	105	190	10	17	162	0.613	−0.66
		1:1	141	59	142	58	79	72	0.383	−0.01
		9:1	198	2	173	27	181	19	1.374	0.571
	4	1:9	189	11	192	8	27	171	1.297	−0.07
		1:1	191	9	191	9	96	105	1.315	0.00
		9:1	197	3	194	6	177	17	1.638	0.145
	5	1:9	115	85	192	8	20	172	0.749	−0.62
		1:1	185	15	162	38	88	87	0.856	0.228
		9:1	197	3	136	64	179	19	1.055	0.728

APPENDIX

(Continued)

Pigeon	Condition	Component	B ₁₁	B ₁₂	B ₂₂	B ₂₁	R ₁₁	R ₂₂	log <i>d</i>	log <i>b</i>
3060	1	1:9	189	11	191	9	25	170	1.271	-0.04
		1:3	186	14	192	8	41	147	1.242	-0.13
		1:1	192	8	193	7	96	101	1.397	-0.03
		3:1	191	9	190	10	154	44	1.292	0.023
		9:1								
	2	1:9	192	8	195	5	14	187	1.469	-0.10
		1:1	191	9	198	2	107	111	1.630	-0.31
		9:1	194	6	193	7	172	19	1.459	0.033
	3	1:9	144	56	196	4	20	167	1.037	-0.63
		1:1	187	13	191	9	87	87	1.233	-0.08
		9:1	200	0	176	24	171	17	1.883	1.021
	4	1:9	188	12	194	6	16	177	1.34	-0.15
		1:1	193	7	191	9	94	102	1.371	0.055
		9:1	196	4	195	5	167	18	1.617	0.047
	5	1:9	187	13	196	4	20	175	1.407	-0.26
		1:1	188	12	192	8	88	102	1.277	-0.09
		9:1	200	0	162	38	177	20	1.766	1.138
1821	1	1:9	171	29	177	23	26	157	0.825	-0.06
		1:3	176	24	179	21	51	137	0.894	-0.03
		1:1	179	21	174	26	87	88	0.874	0.052
		3:1	181	19	171	29	135	47	0.871	0.103
		9:1	176	24	179	21	159	19	0.894	-0.03
	2	1:9								
		1:1								
		9:1								
	3	1:9	78	122	190	10	19	171	0.537	-0.73
		1:1	155	45	155	45	88	95	0.535	0.00
		9:1	173	27	146	54	158	17	0.617	0.186
	4	1:9	171	29	183	17	16	168	0.897	-0.13
		1:1	182	18	173	27	105	92	0.901	0.098
		9:1	184	16	168	32	162	19	0.886	0.169
	5	1:9	147	53	180	20	17	160	0.696	-0.25
		1:1	173	27	159	41	81	90	0.695	0.108
		9:1	185	15	81	119	152	15	0.459	0.626